RESEARCH DEPARTMENT

REFLECTOMETER EQUIPMENT FOR USE AT HIGH-FREQUENCY TRANSMITTING STATIONS

Report No. E-073

(1961/2)

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

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Section	Title	Page
	SUMMARY	1
1	INTRODUCTION	1
2	REQUIREMENTS	2
3	GENERAL DESCRIPTION	2
4	DESCRIPTION OF CIRCUIT	4
5	CALIBRATION OF INDICATORS	5
	5.1. Power	5
	5.2. Reflection Coefficient	6
6	PERFORMANCE	6
	6.1. Indication of Reflection Coefficient	6
	6.2. Operation of Relay	7
	6.3. Power Indication	8
	6.4. Service Trials	8
7	MEASUREMENT OF UNBALANCED CURRENTS	8
8	CONCLUSIONS	9
9	ACKOWLEDGEMENTS	9
10	REFERENCES	10

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SUMMARY

Equipment has been developed for measuring the output power of the transmitters, and the reflection coefficient of the associated balanced transmission lines, at B.B.C. high-frequency (h.f.) transmitting stations. It consists of two directional couplers, one sampling the forward wave (and thus measuring the transmitter power if the reflection coefficient is small), and the other the reflected wave. The outputs from the two couplers are applied to a ratiometer to indicate the reflection coefficient. A fast-operating relay is incorporated to trip the transmitter when the reflection coefficient on the line exceeds a predetermined value. The equipment operates over the frequency range 4-30 Mc/s, and will measure powers up to 200 kW and reflection coefficients up to 75%; it is at present in prototype form, but a design for operational use is being produced in conjunction with the B.B.C. Planning and Installation Department.

1. INTRODUCTION

At B.B.C. h.f. transmitting stations it is required that any one of several aerials may be connected to a given transmitter, and the transmission schedules demand that the change from one aerial to another must be made in the minimum possible time. To meet this requirement and to economise on staff, increased use is being made of remote aerial switching operated from the transmitter hall.

Since, when remote aerial switching is used, all operations are controlled from a central point in the transmitter hall, it is desirable that there should be available at this point:

(a) a means of monitoring the reflection coefficient on the transmission line connected to each transmitter.

(b) a means of protecting the transmitter against damage in the event of an aerial fault, or an incorrect aerial connection, for example the connection of an aerial tuned to a different frequency.

The use of reflectometer equipment offers the best solution to the problem, since it enables the functions (a) and (b) to be carried out by the same apparatus, makes it possible to install the equipment in the transmitter hall, and obviates the need for interlocks associated with each remotely-controlled aerial switch. The use of interlocks on the aerial switches would in any case by undesirable, since the arrangement would be electrically complicated and expensive; furthermore, since the switches are installed in the open air, maintenance difficulties would be increased, possibly leading to a high incidence of faults.

Apparatus for the measurement of power and of reflection coefficient is already widely used at v.h.f. transmitting stations, where reflectometers are coupled to the coaxial output feeders. It would have been possible to apply the same basic design to h.f. transmitters, using a binocular* feeder arrangement, but the system would be cumbersome and expensive. Another design,[1] used at the Prato Smeraldo h.f. transmitting station in Italy, consists of small coupling loops projecting from the tubular conductors of a balanced transmission line. This arrangement has the disadvantage that the transmission line must be interrupted to insert the reflectometer units; in addition, h.f. chokes are required to isolate the reflectometer outputs from the line.

It was therefore decided that a new design should be produced, capable of operating over the whole h.f. band without adjustment, and of being readily attached to any of the types of transmission line in use. These are of the balanced unscreened type, and have a characteristic impedance of approximately 320 ohms. Their form varies from station to station.

2. REQUIREMENTS

The equipment was required to:

(a) give rapid operation of a pair of tripping contacts when the reflection coefficient on the line exceeds a value, preset in the range 30%–75%; this corresponds to standing-wave ratios (s.w.r.s) in the range 0·54–0·14.

(b) be readily removable from the line in the event of failure. This also permits the equipment to be used for other purposes, such as the investigation of faults and mismatches on a transmission line.

(c) be not significantly affected by the presence of stray fields, and by any unbalanced component of the current. In practice this means that the equipment must be capable of discriminating between balanced and unbalanced excitation.

(d) display the reflection coefficient on a meter, in order both to set up the operation of the tripping relay and to provide a check for incipient faults.

3. GENERAL DESCRIPTION

Two short lengths of balanced transmission line, supported parallel to the main line, constitute two separate directional couplers; one samples the forward wave, and the other the reflected wave. The output of each directional coupler is brought into a common central box and detected; the d.c. outputs are then fed through a screened cable to a separate indicating unit. Fig. 1 illustrates the disposition of the reflectometer in relation to the main transmission line. The mechanical construction is shown in Fig. 2.

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*A screened balanced transmission line formed by two unbalanced lines driven in antiphase.

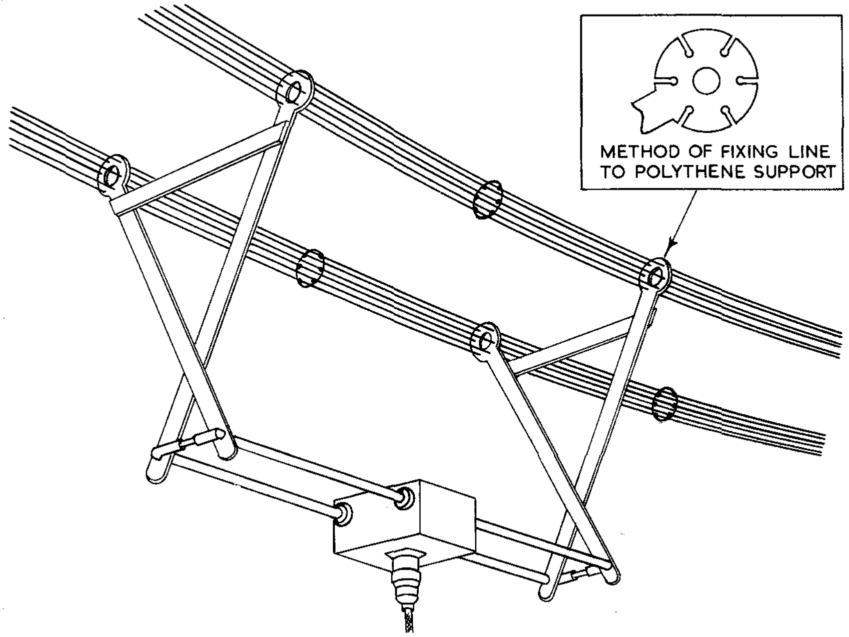

Fig. 1 - Disposition of reflectometer in relation to the main transmission line

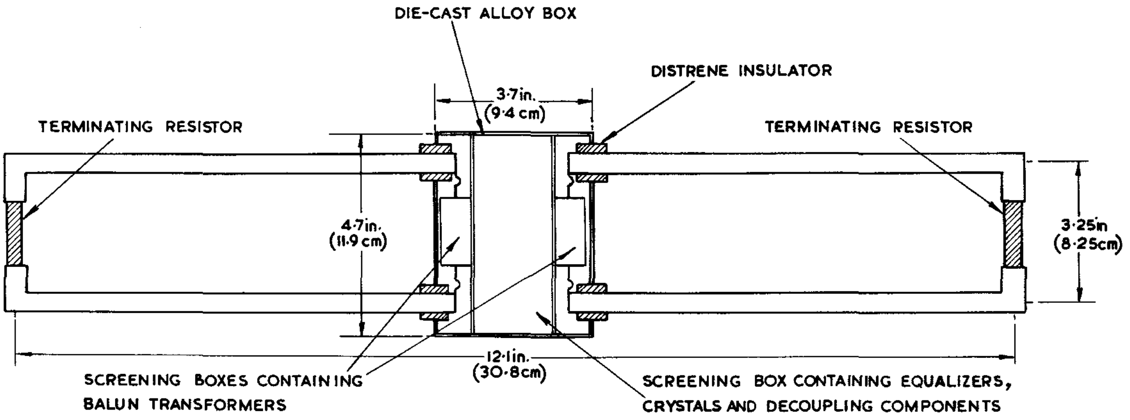

Fig. 2 - Outline diagram illustrating construction of directional couplers

It is undesirable to place the directional couplers too close to the main transmission line, since this might result in voltage breakdown; on the other hand, the spacing must not be so great that stray fields impair the performance. Further, the length of the directional coupler arms and the spacing from the main line must be chosen to give a reasonably compact unit, and to restrict the maximum power handled by each directional coupler to about 2 watts, so that conveniently small components can be used. These factors resulted in the choice of a spacing in the range 10-13 in. (25-33 cm), depending on the form of the main transmission line.

The characteristic impedance of the line forming a directional coupler can be arbitrarily chosen, and is independent of the form of the main line, provided that the coupling is weak (this condition is satisfied in the equipment described). The chosen value of 330 ohms gives a line of convenient dimensions, which may be terminated by a value of resistor in the standard range.

The supporting structure shown in Fig. 1 is made of polythene and is designed to be readily attached to a "sausage" feeder (in which each conductor comprises a group of six wires) without affecting its form. Different arrangements will be required for other types of feeder, but their design is straightforward and will be undertaken when the operational equipment is designed.

4. DESCRIPTION OF CIRCUIT

The circuit diagram of the reflectometer unit is shown in Fig. 3. The output of each directional coupler is fed to the balanced winding of a centre-tapped transformer, having tight coupling between each half of the winding. This results in the directional coupler arms being held at the same potential as the central box as far as unbalanced currents are concerned. This was found to be necessary in order

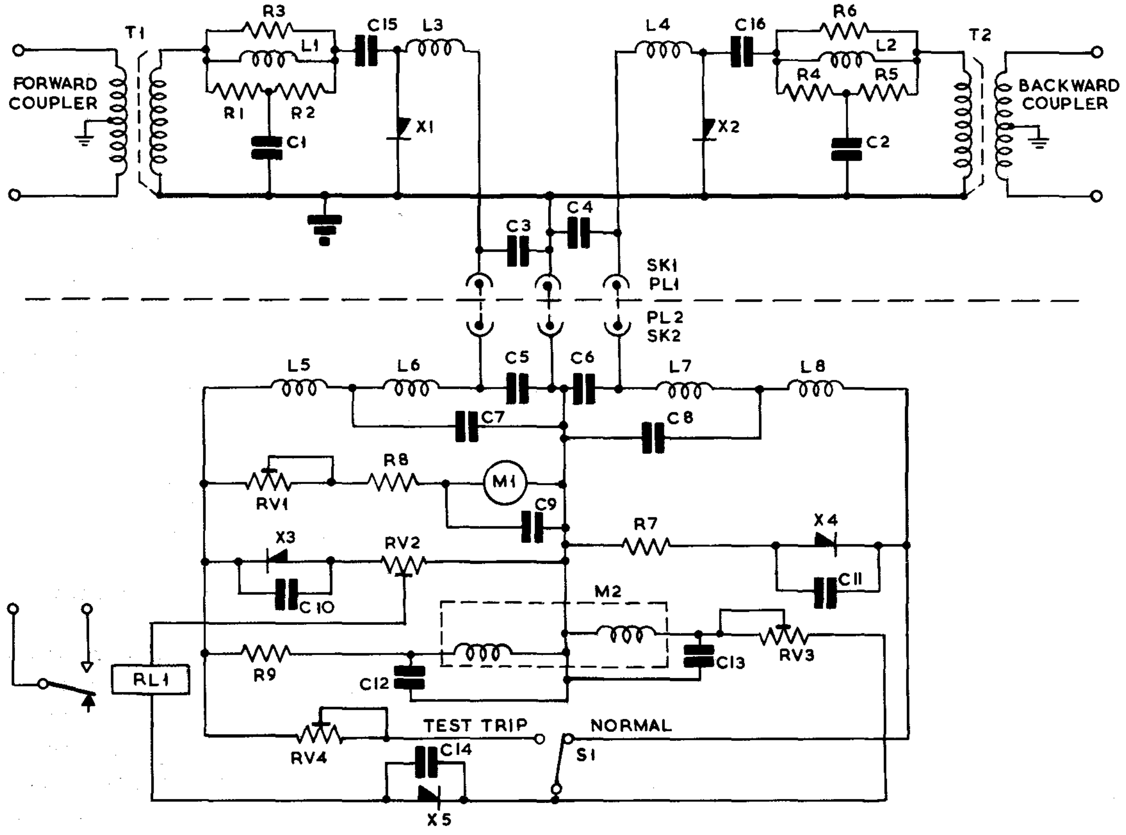

Fig. 3 - Reflectometer - circuit diagram

to reduce the effects of unbalanced currents to a sufficiently low level. The secondary winding of each transformer is unbalanced and is connected to a bridged-T equalizer network with an output/input voltage characteristic which is substantially inversely proportional to frequency. This equalizer compensates the frequency characteristic of the directional coupler, which has an output ratio[2] very nearly proportional to frequency; the power indication is thereby made approximately independent of frequency.

The output from each equalizer is rectified by a crystal diode (X1 and X2), and the direct current is fed by a screened lead to a box containing the power indicator, the reflection coefficient indicator, and the protective relay. In the final form of the equipment it may be convenient to integrate the indicating meters with the transmitter and aerial switching control equipment.

The d.c. load for each detector consists of a similar crystal (X3, X4) in series with a resistor (R7, RV2) in order to improve the linearity of rectification. The voltage developed across the d.c. load of the forward directional coupler is used to operate the 0-100 microammeter, M1, which is calibrated to read power. This voltage also feeds one coil of a ratiometer, M2, which indicates the reflection coefficient. The other coil of the ratiometer is fed from the voltage developed across the d.c. load of the backward directional coupler.

The tripping relay coil, RL1, which has an operating current of 50 μA, is normally connected between the full d.c. voltage from the backward coupler, and a fraction (determined by the setting of RV2) of the d.c. voltage from the forward coupler. The crystal, X3, reduces the variation with output power of the reflection coefficient at which the relay operates; as the power increases the resistance of the crystal decreases, and the fraction of the output voltage appearing at the tapping point of RV2 therefore increases. With the switch S1 in the "TEST TRIP" position, the relay and ratiometer deflection coil are fed with a voltage (controlled by RV4) obtained from the forward directional coupler. This is equivalent to an adjustable reflection coefficient with which to set the operating point of the relay. The crystal X5, in series with the relay coil, prevents current flowing from the forward directional coupler through the relay coil to the ratiometer deflection coil.

5. CALIBRATION OF INDICATORS

5.1. Power

In calibrating the power indicator, two steps are required: first, the output ratio of the directional coupler must be determined accurately, and second, the sensitivity must be adjusted with a known amount of power fed into the forward directional coupler. In order to determine the output ratio, measurements were made on various types of transmission line; calculations were also made based upon formulae derived by Oliver,[3] which apply to two-conductor transmission lines. These measured and calculated values agreed to within ± 0·2 dB. To calibrate the power meter, a known power at a frequency of 18 Mc/s was injected into the arms of the directional coupler. Powers were measured with a specially constructed thermistor wattmeter (with an input impedance of 330 ohms), and also by measuring the voltage developed across a known resistance, taking precautions to ensure that the r.f.

source was free from harmonics. It is estimated that the power injected into the directional coupler was measured to an accuracy of ± 0·5 dB so that, together with the error in determining the output ratio, the overall accuracy of the power calibration at a given frequency was ± 0·7 dB.

5.2. Reflection Coefficient

The reflection coefficient meter was calibrated by injecting known powers simultaneously into the forward and backward directional couplers.

6. PERFORMANCE

6.1. Indication of Reflection Coefficient

The indication of reflection coefficient is independent of frequency, provided that the transformers and equalizing networks have identical characteristics; the remaining sources of error are:

(a) imperfect directivity[2] of the directional coupler

(b) non-linearity in the rectification characteristic.

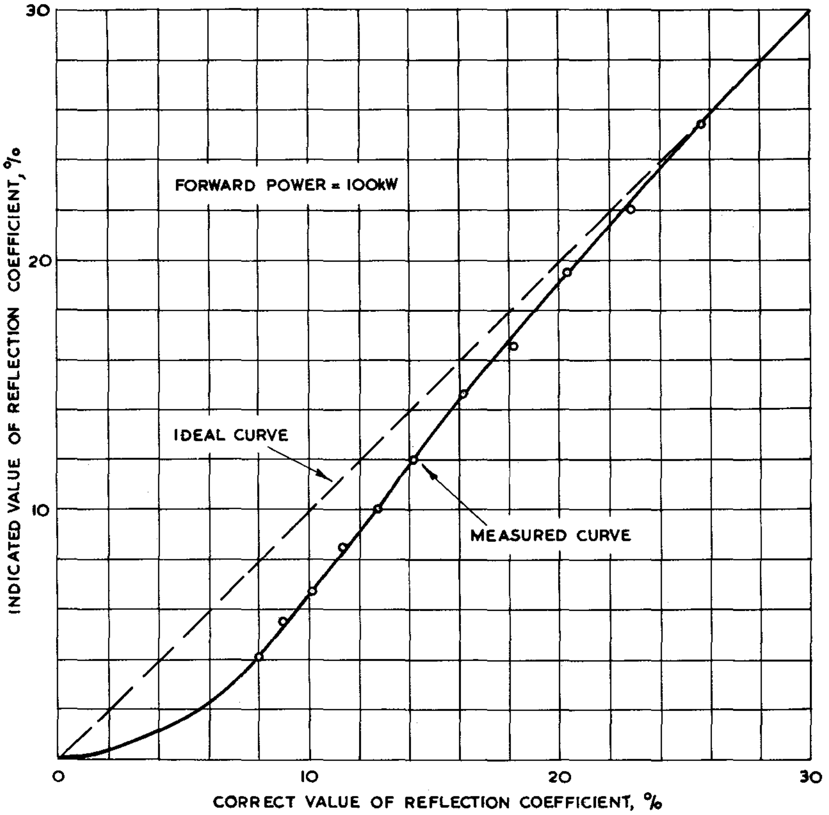

Fig. 4 - Error due to non-linearity in indication of reflection coefficient

Considering (a), imperfect directivity means that the forward wave may produce a small voltage in the backward coupler, so that a reflection coefficient would be indicated, even on a perfectly matched line. The directivity is greater than 30 dB, which is equivalent to a "spurious" reflection coefficient of 3%. Since the reflection coefficients of the aerials are usually in the range 10%–30% this is an acceptable error.

Considering (b), while crystal X3 is effective in correcting non-linearity at the relatively high voltages developed by the forward coupler, the crystal X4 has little effect at the low voltages developed by the backward coupler when the reflection coefficient is low. The indicated reflection coefficient therefore tends to vary as the square of the true reflection coefficient, when the latter is small. Moreover, the actual level at which the indication departs from linearity will depend upon the transmitter output power. At a power of 100 kW, the departure of the indicated reflection coefficient from the true value is shown in Fig. 4.

6.2. Operation of Relay

While the indicated reflection coefficient is governed by the *ratio* of the outputs from the backward and the forward directional couplers, the relay operation is dependent upon the *difference* between the outputs, except insofar as a correction is introduced by the action of the crystals X3 and X4. As the result of insufficient compensation, the value of reflection coefficient at which the relay operates tends to rise as the power output falls, as shown in Fig. 5. In practice, this can be used to advantage, as it permits the transmitters to radiate on reduced power when the reflection coefficient of the array is high as the result of heavy icing conditions.

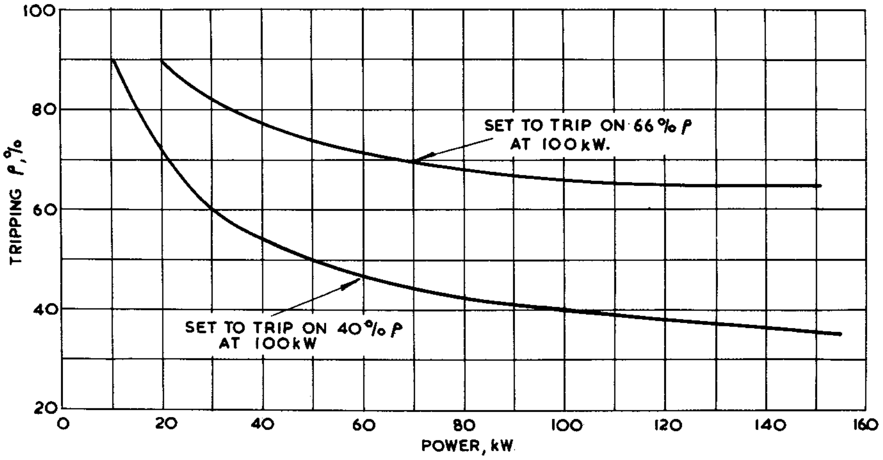

Fig. 5 - Variation, with power, of the value of reflection coefficient, ρ, at which the relay operates

6.3. Power Indication

It has been seen that, in order to obtain an indication of power that is independent of frequency, it is necessary to insert an equalising network in the output of each directional coupler. The frequency characteristic of this network does not in practice exactly compensate for the characteristic of the directional coupler; both on this account and because of variations in the insertion loss of the transformer, the indication on the power meter depends to some extent upon frequency. Fig. 6 illustrates this frequency dependence, and shows that, if the meter is calibrated correctly at the centre of the band, the error is less than 0·4 dB throughout most of the frequency band for powers exceeding 10 kW.

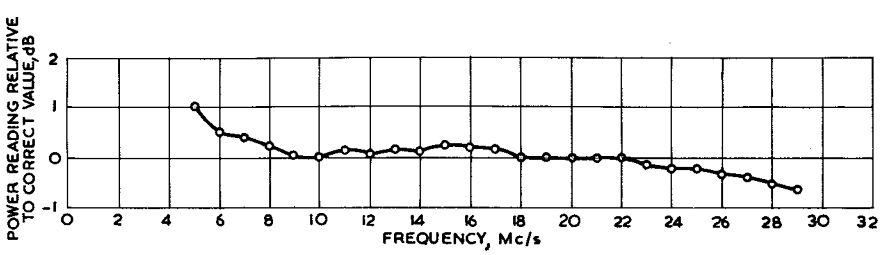

Fig. 6 - Variation of power reading with frequency

There will be an additional error in the measurement of transmitter power since the indication is of forward power flow. This may be corrected by multiplying the indicated power by $(1 - \rho^2)$, where ρ is the reflection coefficient.

6.4. Service Trials

Tests upon prototype models of the equipment have been carried out at three B.B.C. h.f. stations. In each case it was found that stray fields were sometimes very high, and it has been necessary to adopt very thorough screening in the equipment, and to apply decoupling capacitors at many points in the d.c. circuits; the use of the balanced/unbalanced transformers has also been very helpful in this respect. As a result of the measures adopted, it is estimated that stray fields give rise to errors not exceeding 1·5 kW in measuring power, and 2% in measuring reflection coefficient. It should, however, be borne in mind that the equipment will give an indication even when the transmitter is switched off, if power flows in the line due to adventitious coupling with other arrays.

7. MEASUREMENT OF UNBALANCED CURRENTS

The main transmission lines may carry unbalanced or "push-push" currents owing to imperfect balance of transmitter or aerial, or to inequality of the lengths of the two conductors comprising the line. Such currents are undesirable since, apart from loss of power by dissipation in the ground, there will be unwanted radiation.[4] It is possible that the equipment described could be used for the measurement of such unbalanced currents, by rotating it through a right angle so that the arms of the directional coupler lie parallel to the main feeder in a vertical plane.

8. CONCLUSIONS

The equipment has been tested under service conditions and found to be satisfactory for use at high-frequency transmitting stations. A design suitable for production and issue to h.f. stations is being produced in collaboration with the B.B.C. Planning and Installation Department. The characteristics may be summarised as follows:

(a) A meter is provided to monitor the output power of the transmitter. Provided the reflection coefficient does not exceed 15% the error is within ± 0·7 dB, plus a possible error of ± 1·5 kW due to stray fields; thus for powers exceeding 50 kW the overall error may be taken to be ± 0·8 dB. If no correction is made for the frequency variation shown in Fig. 6 there will be an additional error of ± 0·4 dB, making a total of ± 1·2 dB. If the reflection coefficient exceeds 15% the indicated power should be corrected by multiplying by $(1 - \rho^2)$, where ρ is the reflection coefficient.

(b) The transmitter can be tripped when the reflection coefficient exceeds a value which may be preset in the range 30%–75%. When the equipment is set to trip for a predetermined reflection coefficient and a given transmitter power, the error in the reflection coefficient at which the trip operates will not exceed that of the reflection-coefficient meter.

(c) A ratiometer is provided to monitor the reflection coefficient on the transmission line. For powers of 100 kW and above the only errors in indication arise from imperfect directivity and stray fields. These errors are equivalent to spurious reflection coefficients of 3% and 2% respectively, making a maximum possible error of 5%. For reflection coefficients less than 20% a correction should be applied for the non-linearity of the detector, as shown in Fig. 4.

9. ACKNOWLEDGEMENTS

The staffs of both the Planning and Installation Department and the Operations and Maintenance Department (Transmission) have co-operated in the development of the equipment described. Planning and Installation Department provided information regarding the transmission lines, and is arranging for the production of standard equipment to issue to h.f. transmitting stations. The staffs at the Daventry, Rampisham and Skelton stations arranged the necessary facilities, and assisted in the practical tests.

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